A 14: Precision Spectroscopy of atoms and ions IV

Time: Wednesday 10:30–12:15 Location: S HS 2 Physik

A 14.1 Wed 10:30 S HS 2 Physik

High-resolution astrophysical applications of the PolarX-EBIT — •Steffen Kühn[1], Sven Bernitt[2], Peter Micke[1], Michael Karl Rosner[1], Chintan Shah[1], René Steinbrügge[3], Moto Togawa[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Friedrich-Schiller-Universität Jena — [3]Deutsches Elektronensynchrotron, Hamburg

For the interpretation of x-ray emission lines of stellar sources in astrophysics, a good knowledge of fundamental atomic parameters of Highly Charged Ions (HCI) is crucial. High resolution observations of the Perseus cluster by the Hitomi satellite mission showed a variety of lines for which atomic databases are incomplete or incorrect. For the upcoming satellite missions, e.g. XRISM and Athena, it is vital to fill these gaps for the most abundant elements in space.

For this application we developed a compact electron beam ion trap (EBIT) employing an off-axis gun, leaving the main axis free of any obstacles, which allows to install the EBIT parasitically at high brilliant photon light sources such as synchrotrons for photon plasma interaction investigations.

We demonstrate high-precision measurements of dielectronic recombination and resonant photo excitation of Ne- up to He-like systems. Furthermore, we were able to shed a light on an astrophysical puzzle regarding the interstellar atomic oxygen 1s-2p absorption line energy deviating from laboratory measurements, which led to the dubious conclusion that the mean radial velocity of the atomic oxygen in the interstellar medium is 340km/s larger than the galactic escape velocity.

A 14.2 Wed 10:45 S HS 2 Physik

Interplay between Coulomb and nuclear forces in the low-energy three-body reaction $\bar{\mathrm{p}} + {}^2\mathrm{H}_\mu \to (\bar{\mathrm{p}}\mathrm{D}) + \mu^-$ — •Renat A. Sultanov — 201 W. University Blvd., Department of Mathematics and Engineering, Odessa College, Wood Building of Math and Science (WOOD) Room 213, Odessa, TX 79764

Since $\bar{\mathrm{p}}$ is an antibaryonic particle with the baryonic number $B = -1$, it would be interesting to discover the strong nuclear interaction between, for example, $\bar{\mathrm{p}}$ and a proton, p. This is also known as the $\bar{\mathrm{p}}$-p interaction in a protonium atom - a bound state of the particles: Pn $= (\bar{\mathrm{p}}\mathrm{p})_\alpha$. The two-body system is also called antiprotonic hydrogen. Additionally, it would be useful to consider and compare results of similar Coulomb-nuclear atomic systems: $\bar{\mathrm{p}}$-D and $\bar{\mathrm{p}}$-T, where D$={}^2\mathrm{H}^+$ is the deuterium nucleus and T$={}^3\mathrm{H}^+$ is tritium. It is possible to prepare such atomic systems with the use of muons [1,2], for example, in the framework of the three-body reactions:

$$\bar{\mathrm{p}} + (\mathrm{p}\mu^-) \to (\bar{\mathrm{p}}\mathrm{p})\alpha + \mu^-, \quad \text{and} \tag{1}$$

$$\bar{\mathrm{p}} + (\mathrm{D}\mu^-) \to (\bar{\mathrm{p}}\mathrm{D})\alpha + \mu^-. \tag{2}$$

Here: μ^- is a negative muon and α is the final atomic state of Pn or the $\bar{\mathrm{p}}$D atoms. In the current work, a detailed few-body treatment is carried out for these low-energy reactions with the use of a set of coupled few-body Faddeev equations and a modified close coupling approximation approach.

1. R.A. Sultanov et al., Few-Body Systems, (Springer) 56, 793 (2015).

2. R.A. Sultanov et al., Atoms (MDPI) 6, 18, (2018).

A 14.3 Wed 11:00 S HS 2 Physik

The Alphatrap g-factor experiment — •Tim Sailer[1,2], Ioanna Arapoglou[1,2], Hendrik Bekker[1], José R. Crespo López-Urrutia[1], Alexander Egl[1,2], Martin Höcker[1], Bingsheng Tu[1], Andreas Weigel[1,2], Robert Wolf[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Fakultät für Physik und Astronomie, Universität Heidelberg

The Penning-trap experiment Alphatrap, located at the Max-Planck-Institut für Kernphysik, aims to measure the g-factor of bound electrons in highly charged ions (HCI) up to hydrogenlike ${}^{208}\mathrm{Pb}^{81+}$. In the electrical field of the nucleus with a strength of the order of 10^{16} V/cm, bound-state quantum electrodynamics can be tested with highest precision in extreme conditions. So far, a table-top Electron Beam Ion Trap (EBIT) has been used successfully to produce and inject ions up to ${}^{40}\mathrm{Ar}^{13+}$ into the trap. Furthermore, a laser ion source (LIS) has been attached to the beamline and tested to produce and inject ${}^{9}\mathrm{Be}^{+}$ ions. These will be used for sympathetic laser cooling of the HCI which lack suitable transitions for direct laser cooling.

To produce heavy HCI, which requires ionization energies on the order of several 10 keV, the Alphatrap setup has been connected via a UHV beamline to the Heidelberg-EBIT. The extraction of the produced HCI, their transport and injection into the Alphatrap setup are in the final phase of the commissioning of which the first results will be presented.

A 14.4 Wed 11:15 S HS 2 Physik

g-factor Measurement of Boronlike ${}^{40}\mathrm{Ar}^{13+}$ at Alphatrap — •Bingsheng Tu[1], Ioanna Arapoglou[1], Alexander Egl[1], Martin Höcker[1], Tim Sailer[1], Timo Steinsberger[1,2], Andreas Weigel[1], Robert Wolf[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Fakultät für Physik und Astronomie, Universität Heidelberg, 69120 Heidelberg

The Alphatrap experiment is a Penning-trap setup to perform high-precision g-factor measurement on highly charged ions (HCI) up to hydrogenlike ${}^{208}\mathrm{Pb}^{81+}$. By determining the bound eletron's g-factor, the most stringent test of Bound-State Quantum Electrodynamics (BS-QED) in the strong field can be carried out. Furthermore, Alphatrap can provide access to fundamental constants, such as the fine-structure constant α or the electron's atomic mass. The first measurement campaign of Alphatrap has been dedicated to the determination of the ground-state g-factor of a single boronlike ${}^{40}\mathrm{Ar}^{13+}$. Using non-destructive detection techniques for the stored ion's motion, the cyclotron as well as the Larmor frequency can be determined, allowing for a parts per billion precision measurement of the g-factor. Prominent systematic effects in predecessor experiments are highly suppressed in our optimised setup. The leading systematic effect during this measurement is the axial frequency drift, caused by the slow thermalisation of the voltage source. In this contribution the Alphatrap status, its results on ${}^{40}\mathrm{Ar}^{13+}$ as well as the future perspectives will be presented.

A 14.5 Wed 11:30 S HS 2 Physik

Quantum electrodynamic effects in many-electron highly charged ions — •Halil Cakir[1], Vladimir A. Yerokhin[2], Natalia S. Oreshkina[1], Bastian Sikora[1], Zoltán Harman[1], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

Highly charged ions provide a natural source of strong electric fields and, thus, allow us to test QED predictions under extreme conditions. For these kinds of systems, perturbative expansions in the nuclear coupling strength $Z\alpha$ are not feasible and calculations need to be done to all orders in $Z\alpha$.

A combination of experimental and theoretical values of the g-factor of hydrogen-like ions allowed a significant improvement of the electron mass in terms of atomic mass units in the past and a similar interplay of experiment and theory for highly charged boron-like systems is expected to provide a new access to the value of the fine-structure constant [1] (see also [2]). In this context, we present calculations of the theoretical contributions to the g-factor of boron-like Ar^{13+}, which has been recently measured by the ALPHATRAP Penning-trap setup at the Max Planck Institute for Nuclear Physics. – [1] V. M. Shabaev *et al.*, Phys. Rev. Lett. **96**, 253002 (2006); [2] V. A. Yerokhin *et al.*, Phys. Rev. Lett., **116**, 100801 (2016).

A 14.6 Wed 11:45 S HS 2 Physik

Towards setup, characterization and operation of a highly charged ion beamline. — •Michael K. Rosner[1], Sandra Bogen[1], Steffen Kühn[1], Julian Stark[1], Moto Togawa[1], Christian Warnecke[1], Peter Micke[1,2], and José R. Crespo López-Urrutia[1] — [1]Max-Planck Institut für Kernphysik, Heidelberg — [2]Physikalisch Technische Bundesanstalt

Highly charged ions (HCI) have high sensitivity to quantum electrodynamics and other fundamental interactions, making some species candidates to test the time variation of the fine-structure constant $\dot{\alpha}$. They are a promising target for high precision laser spectroscopy, aiming to measure their narrow optical transitions using quantum logic spectroscopy, as recently been demonstrated on Ar^{13+}.

While an electron beam ion trap (EBIT) produces ions in the necessary charge states, the spectral resolution there is limited by Doppler broadening. This requires the transfer of the HCI into a cooler trapping environment, in our case a Coulomb crystal of laser-cooled Be^+ ions prepared in a superconducting Paul trap.

We present a beamline between an EBIT and a Paul trap we designed to transfer, bunch and decelerate the HCI while also providing vibration decoupling between the Paul trap and its environment. It consists of an arrangement of ion optics, diagnostic elements and a decelerating unit. We perform time-of-flight measurements in order to determine the charge state distributions of extracted ions as well as their kinetic energy spread.

A 14.7 Wed 12:00 S HS 2 Physik

Development of a Low-Emittance Laser Ablation Ion Source
— •Tim Ratajczyk[1], Philipp Bollinger[1], Tim Lellinger[1], Victor Varentsov[2,3], and Wilfried Nörtershäuser[1] — [1]Institut für Kernphysik, TU Darmstadt — [2]Facility for Antiproton and Ion Research in Europe (FAIRGmbH), Darmstadt — [3]Institute for Theoretical and ExperimentalPhysics, Moscow, Russia

Ion sources of low-emittance are of interest in many applications of experimental low-energy physics, for example as ion sources for collinear laser spectroscopy or ion trap experiments, or as ion sources for accelerators. Often, surface ion sources are used due to their simple construction and easiness of operation. However, they can only deliver a very small range of elements, mostly alkaline and alkaline earth ions and a few other species. We are developing a more versatile ion source based on ion creation by laser ablation inside a helium buffer gas cell and extraction through optimized RF funnels. The design is based on a RF-only ion funnel design, but extended by a second compact original RF-funnel that allows for bunching of the beam and even better performance. We expect a supreme ion beam quality that will first being studied by collinear laser spectroscopy to determine its longitudinal emittance and present the current status of the buffer gas cell, the extraction funnels and a compact collinear laser spectroscopy design.